UNIVERSITY OF NEVADA
MACKAY SCHOOL OF MINES
RENO, NEVADA 89507

Geology-Geography Department
Seismological Laboratory

TO: Mr. William J. Best, Chief
Geophysics Division
Office of Aerospace Research, USAF
1400 Wilson Blvd.
Arlington, Virginia 22209

SUBJECT: Final Report

REPORT DATE: 18 June 1970

GRANT NUMBER: AFOSR 69-1820

ARPA ORDER NUMBER: 292

PROGRAM CODE: 9f10

GRANTEE: University of Nevada at Reno

PROJECT SCIENTISTS: Gary W. Boucher and Alan S. Ryall Tel. No. (702) 784-6691

STARTING DATE OF GRANT: 14 April 1969

TERMINATION DATE OF GRANT: 14 April 1970

AMOUNT OF GRANT: $19,760.00

TITLE OF WORK: Seismicity, mechanics of faulting and crustal structure within the Basin and Range and adjoining provinces.

MACKAY SCHOOL OF MINES
NEVADA BUREAU OF MINES . NEVADA MINING ANALYTICAL LABORATORY
CHEMICAL AND METALLURGICAL ENGINEERING DEPARTMENT . GEOLOGY–GEOGRAPHY DEPARTMENT . MINING ENGINEERING DEPARTMENT

23

STRAIN EFFECTS OF NUCLEAR EXPLOSIONS IN NEVADA

Gary Boucher, Stephen D. Malone, and E. Fred Homuth

Abstract

The University of Nevada's 3 component quartz-rod strainmeter installation at Round Mountain, Nevada (38°42.1' N, 117°04.6' W) has recorded a number of underground nuclear explosions at the Nevada Test Site, beginning with the megaton-sized JORUM event September 16, 1969. That explosion, and the larger HANDLEY event on March 26, 1970 both produced static strain offsets of a few parts in 10^9 at Round Mountain. These offsets did not decay within the first few hours after the explosions. In both cases the strain offsets were in the sense of ground extension radial to the shot point, which is inconsistent with the assumption of a pure compressive source of strain. The strain change ellipse for the HANDLEY event was found to have a major strain axis of 11.1×10^{-9} extensional, oriented N 34°W, and a minor axis of 7.39×10^{-9} compressional. A single-component strainmeter at Mina, Nevada, (38°26.3' N, 118°9.3' W) was operated for the HANDLEY event, and recorded a strain offset of 2.6×10^{-9} in the direction N 74°E. Strain offsets at the time of the largest collapse events following HANDLEY were observed at Round Mountain. These offsets had the same sense on each component as those following the explosion itself. This is interpreted as support for the hypothesis that the strain changes are tectonic in origin, and the explosion initiates the strain release. Small offsets were observed for three smaller explosions out of a total of 13 studied. The relationship between body-wave magnitude m_b and maximum dynamic strains at Round Mountain may be described empirically by the equation $\text{Log } S = -13.4 + 1.10\, m_b$. Because of its high sensitivity and stability, the Round Mountain strain meter is

capable of obtaining useful measurements of dynamic and static strain effects of intermediate- to large-sized explosions, at distances ranging from 160 to 200 km.

Strain Effects of Nuclear Explosions in Nevada

Introduction

The Seismological Laboratory of the University of Nevada has operated a strain seismograph system at Round Mountain, Nevada, intermittently since October, 1969, and continuously since early 1970. A station near Mina, Nevada, was temporarily operated for the HANDLEY explosion on March 26, 1970. During this period, the station at Round Mountain has recorded a number of underground nuclear explosions from the Nevada Test Site in addition to numerous earthquakes. The purpose of this paper is to summarize and discuss the observations to date, exploring their bearing on the question of strain release by underground explosions.

The results from two large explosions, JORUM and HANDLEY are in accord with earlier observations (Romig *et al.*, 1969) that static strain changes occurred when the megaton-sized explosion BENHAM was detonated. However, the observations for JORUM and HANDLEY have not shown the decay with time that was noted for the earlier explosion. Instead, the strain changes appear to be permanent, at least over a period of many hours. Similar results have been reported by Smith and Archambeau (1969) and by Romig *et al.* (1969). Additional results showing strain offsets from some of the smaller tests as well as from some of the 'collapse' events following the HANDLEY shot will be discussed.

The events on the Nevada Test Site (NTS) were fired over a distance range of 160 to 210 km from both the Round Mountain and Mina strain meter sites. The sensitivity of these stations to strain effects of explosions is thus somewhat reduced by distance, but because of their relatively high stability and sensitivity compared with the existing on-site strain

meters, the effects of distance are to some degree compensated. Round Mountain and Mina fill a large gap in the azimuthal distribution of strain meters around the NTS, and are the only such installations in this range of distance. It is noteworthy that significant strain offsets from explosions can be observed at distances of this order.

Instrumentation

The Round Mountain strain meter (38°42.1'N, 117°04.6'W) is located in an abandoned gold mine, at a depth of about 400 feet beneath the valley floor. The surface elevation at the site is approximately 6200 feet above sea level. The orientations of the strain meters at Round Mountain are N72°W, N12.5°W, and N35.5°E. The recording instrumentation is located in a drift at an intermediate depth down the access shaft. The air circulation through the mine has been closed off, and an insulated bulkhead in the access shaft helps to stabilize the environment. The strain meters themselves are isolated by well-grouted concrete bulkheads with air tight doors.

The strain meter at Mina (38°26.3'N; 118°9.3'W) is located in a tunnel about 150 m deep in a mountainside. The orientation of the Mina strain meter is N74°E. The tunnel had not been sealed off at the time of the HANDLEY shot, and the recording trace shows large amplitude noise associated with the passage of a weather front at the time of the explosion.

The strain meters are of a type employed in several other installations, utilizing 80 foot quartz tubes as the standard of length, with a Benioff-type capacitive transducer. Recentering and direct calibration of the transducer are provided by the transducer mounting, designed at the Colorado School of Mines (Romig, 1967), which uses a differential micrometer

screw driven by a motor, with remote detection of the screw position. Continuous signals are normally recorded at 1.5 inches per hour on Hewlett-Packard 10" chart recorders, using an electrostatic writing process for added reliability. An automatic recorder recentering device developed at the University of Nevada provides an equivalent of 90 inches of chart width in order to keep the recording trace on scale over long periods of unattended operation. Several months after the instrument drifts were closed off the upper limit on drift rates has fallen to approximately 5×10^{-8} per month in equivalent earth strain. The instruments have not been in operation long enough at this writing to make any comments on secular strains, except that they are evidently smaller than a few parts in 10^{8} per month at most. The noise level on the recordings is less than 5×10^{-10} equivalent strain for periods under a few minutes, but noise at periods of an hour to a few hours, probably atmospheric in origin, may be a factor of 10 larger. This noise places a lower limit of about 3×10^{-10} on the size of strain offset that can be identified with confidence.

The stability of the strain seismograph system under large disturbances appears to be excellent, as has been shown by loading the quartz heavily and driving it wildly off scale, after which the trace returns to its original position. Furthermore, sizable dynamic strain events, such as explosions of intermediate yield and moderate earthquakes commonly show no offset. For these reasons, it is believed that the observed strain offsets are real, and are not due to instabilities in the detection or recording systems.

Dynamic strain observations

'Dynamic strain' is used to describe the transient strain signal

produced by an earthquake or explosion, as opposed to the permanent or semi-permanent strain offsets that may be observed. The JORUM explosion (distance 165 km, azimuth S19°E) was recorded at low gain on an auxiliary chart recorder. For the HANDLEY shot, (distance 162 km; azimuth S17.6°E), a tape-recording at greatly reduced sensitivity was made of the dynamic strain, to measure the largest strains. In this case, the largest strains appeared to be associated with the surface wave portion of the signal, and the maximum peak-to-peak strains observed on the N12.5°W, N72°W, and N35.5°E components were, respectively, 28.9×10^{-7}, 12.7×10^{-7}, and 9.91×10^{-7}. These are conservative, since the transducer is not truly linear for such large strains. The orientation of the N12.5°W instrument is very nearly radial to the sites of HANDLEY and JORUM. Invoking the angular sensitivity of strain meters to longitudinal and transverse waves, it is of interest to note that these observations can be accounted for by assuming that the surface wave motion is all of the Rayleigh type. Since the non-radial components are favorably oriented for recording Love waves, it is apparent from examination of the tape recordings that the Love wave amplitudes are at most one-fourth as large as the Rayleigh amplitudes at Round Mountain.

Data on dynamic strains have been gathered for a number of smaller underground nuclear explosions on the Nevada Test Site, most of which were fired in the Yucca Flats area of NTS. For reference, these data (averaged when more than one component is available), are shown in figure 1 as a function of body wave magnitude (m_b) as determined by the U.S. Coast and Geodetic Survey's Preliminary Determination of Epicenters. Without discussing the consistency of these magnitude determinations from shot to

shot, it is apparent that the data group around a line Log A = -13.4 + 1.10 m_b, where A is the peak-to-peak maximum strain amplitude. A distance-scaling law of 1/r was used for those events located away from the main concentration of epicenters, as is appropriate for the assumption of surface waves propagating in a layer on a halfspace. These data are a useful aid to determine the appropriate sensitivity for use in a given experiment.

Static strain offsets

Strain recordings of large underground nuclear explosions sometimes show offsets that appear to be of a permanent or semi-permanent nature, in that the offset remains after the transient strains from the earthquake have died out, (Romig, *et al.*, 1969; Smith, *et al.*, 1969; Boucher, *et al.*, 1969). The N12.5°W component of the Round Mountain strain seismograph was in operation for the explosion JORUM, and an apparently permanent strain offset of 5.6×10^{-9} nearly radial to the shot direction was observed, in the sense of ground extension. The observed residual strain change could not be directly related to the pressure in the shot cavity, since on a radial component a pure explosive source would be expected to result in a compressive residual strain, if any (Romig, *et al.*,1969).

At the time of the HANDLEY shot, three components of the strain seismograph at Round Mountain were in operation as well as one component at Mina, and large residual strains were observed on all instruments. The strain steps observed on the N12.5°W, N72°W, and N35.5°E components were approximately 8.55×10^{-9}, 5.15×10^{-9}, and 4.86×10^{-9}, respectively. The strain seismograms are shown in figure 2, and the data are presented graphically in figure 3, along with the single observation from the Mina

strain meter site where an extensional offset of 2.58 x 10^{-9} was seen in the direction N74°E. The strain change ellipse calculated for the data from Round Mountain is shown on the figure for Round Mountain. Again, the component nearly radial to the shot point, N12.5°W, shows a net extensional strain.

In none of the observations, either from JORUM or HANDLEY, was there any indication of a decay in the strain step, as had been reported for the BENHAM explosion in 1968 (Romig, et al., 1969). However, the first 10 minutes or so after the shot are lost on the high sensitivity records. Figure 4 shows the digitized strain data from Round Mountain, superimposed upon calculated earth tides for a period of 12 hours around the time of the HANDLEY explosion. These theoretical earth tides were calculated using a modification of a computer program originally prepared by J. C. Harrison of the University of Colorado. Comparison of the data with the calculated tides has indicated that the theoretical North-South tidal strain, used to calculate the strain components shown, may be slightly in error in the relative amplitude of the semidiurnal tide, but the other two components fit the data well in phase and relative amplitude. This problem is still under investigation, but the purpose of figure 4 is to show that recovery of the strain offsets, at least within the first 7 hours after the explosion, is unlikely. As mentioned previously a storm front was crossing central Nevada at the time of the test, with the result that the traces show some sizable irregularities. These fluctuations are not as large as the strain offsets, however, and do not affect the conclusion about the permanency of the strain offset. Incidentally, figure 4 shows the magnitude of the strain steps as observed at Round Mountain, relative to the size of the earth tidal strains.

These isolated observations are not sufficient in themselves to make any specific evaluation of the type of strain release caused by the explosions, since they must be combined with the data gathered by other laboratories operating strainmeters on and near the NTS. It is clear, however, that the naive assumption of a point compressive source of strain is inadequate to explain the data. Additional data gathered from some of the 'collapse' events following HANDLEY may provide some insight into the mechanism of the strain changes caused by large explosions. Figure 5 shows the Round Mountain strain records from approximately 1630 to 1930 GMT on March 27, the day after the HANDLEY shot. At this time, the sensitivities of the instruments had been reduced by 50%. The two largest events, which occurred around 1808 and 1818 have been identified as characteristic collapse-type events originating at the HANDLEY site (R. M. Hamilton, personal comm.). Although these events are not large, with magnitudes around 4.9 and 5.3, there appear to be small strain offsets associated with them. An extensional offset seems quite definite on the N70°W component, and the combined offset for the two events is about 7×10^{-10}. On the N15°W component the offset is apparently of the same order and sense, although the trace is noisier. The offset, if any, on the N35.5°E component is too small to be identified with certainty, since there is substantial noise, but there is an indication that the first event, at least, may have a small compressional offset. At least the two offsets that appear to be definite are of the same type as those observed for the explosion itself. The offset on N35°E, though marginally detectable, appears to be in the same direction as the offset from the explosion. One may then hypothesize that the strain offset observed at the time of

the collapse events is similar to that caused by the explosion in the distribution of compressions and extensions, even though there may not necessarily be a direct proportionality from component to component. Other strain data may, of course, indicate that the overall strain change pattern of the collapse events was different from that of the explosion.

Based upon the observations at Round Mountain, one may make the following analysis of the strain changes caused by the HANDLEY explosion and the collapse events. Only two sources of strain energy were available. Either there was pre-existing tectonic strain energy present before the explosion, or else the explosion provided all the energy. It is difficult to imagine how a point compressive stress source like an explosion could have produced the strain changes seen at Round Mountain at the time of both the explosion and the collapse events. Perhaps one might argue on the one hand that the effect of the explosion is to disturb the previously unstressed firing medium so violently that the resulting strain pattern cannot be predicted. But a consequence of this is that the resulting strain pattern must be one of higher energy than before, the energy being supplied by the explosion. In other words, a non-equilibrium condition is introduced by the explosion. It is then difficult to explain how a later event, whose energy is drawn from the non-equilibrium elastic strain, could induce strain changes not in the direction of equilibrium. Yet the Round Mountain strain offsets of the collapse events are not in the direction of recovery of the explosion-induced strain. On the other hand if both the explosion and the collapse events released pre-existing elastic strain, it is easy to reconcile the observed strain changes with a plausible mechanism. The

strain offsets due to the explosion and to the collapse events would be analogous to an earthquake and its aftershocks, respectively, whereas the explosion and the collapse events themselves clearly do not partake in the analogy, since they are not related to the regional tectonic strain and serve only as "triggering" effects for strain release. Support for this last statement is provided by studies of Ryall and Savage (1969) and Bakun and Johnson (1970), who reported that the collapse events are fundamentally different from earthquake events.

The radial strain offset observed for the HANDLEY explosion is about 1.5 times as large as that observed for JORUM. This may be explained equally well by the larger size of HANDLEY, by a different mechanism of strain release, or by the fact that HANDLEY was fired at some distance from the location of all previous shots, in a different geological environment.

Of the 11 other NTS explosions observed during this period of operation of the Round Mountain installation, only 3 have produced apparent strain offsets. Events, classed as 'low' or 'low-intermediate' yield are just too far away from Round Mountain for offsets to be visible in most cases, even if they exist. The three exceptions were as follows: YANNIGAN (m_b = 5.3) had a compressional offset of about 6.1 x 10^{-10} on the N15°W component, which appeared to decay within 15 minutes or so. SHAPER (m_b = 5.5) had an extensional offset on the N12.5°W component of about 8.2 x 10^{-10}, which did not appear to decay. DIANA MIST (m_b = 4.6) had apparent extensional offsets of about 3 x 10^{-10} on the N35.5°E and N12.5°W components although these are of the same order as the record noise. Data were not available from the N72°W component for most of these smaller explosions prior to April, 1970 due to operating difficulties.

CONCLUSION

The purpose of this paper has been to present some data and discussion relative to the general problem of tectonic strain release by large underground explosions, and in so doing to demonstrate that a strain meter installation located as much as 200 km from moderate to large sized nuclear tests can obtain useful information on tectonic strain release caused by those explosions. The Round Mountain strain meter site operates at substantially higher sensitivity, and with greater stability than the existing strain meters located on the NTS. The fact that the stability of the instruments at Round Mountain permits correlation of the strain observations with theoretical earth tides has helped to establish that the strain offsets due to the HANDLEY explosion remained completely static for at least 7 hours after the explosion. Furthermore, at the time of the largest collapse events some 23 hours after the explosion, the strain changes seem to have been in the same general sense as the offsets resulting from the explosion itself. This appears to support the hypothesis that tectonic strain stored in the earth's crust was released through some triggering mechanism by the explosion and later by its collapse events.

ACKNOWLEDGMENTS

This research was supported partly by the National Science Foundation under grant GP 5034 and partly by the Advance Research Projects Agency under grant AFOSR 69-1820, monitored by the Air Force Office of Scientific Research. The Ordrich Gold Reserves Corporation of Round Mountain, Nevada, graciously granted permission to use its workings and other facilities for the strain meter installation at Round Mountain.

References

Boucher, G., A. Ryall, E. F. Homuth, and W. U. Savage (1970). Strain and field-seismic observations of effects due to the Nevada underground nuclear test JORUM, Abstract, _Trans._, Amer. Geophys. Union, _51_, 203.

Bakun, W. H., and L. R. Johnson (1970). Short period spectral discriminants for explosions, Abstract, _Trans._, Amer. Geophys. Union, _51_, 354.

Romig, P. R., (1967). A millimicron displacement transducer with mechanical calibration, Colo. School of Mines _Grad. Thesis_ T1123, 59 pp.

Romig, P. R., W. M. Major, C. J. Wideman, and Don Tocher (1969). Residual strains associated with a nuclear explosion, _Bull. Seism. Soc. Am._ _59_, 2167.

Ryall, A., and W. U. Savage (1969). A comparison of seismological effects for the Nevada underground test BOXCAR with natural earthquakes in the Nevada region, _Jour. Geophys. Res._, _74_, 4281.

Smith, S. W., and C. B. Archambeau (1970). Tectonic strain readjustments as a result of a large underground explosion, Abstract, _Trans._, Amer. Geophys. Union, _51_, 203.

FIGURE CAPTIONS

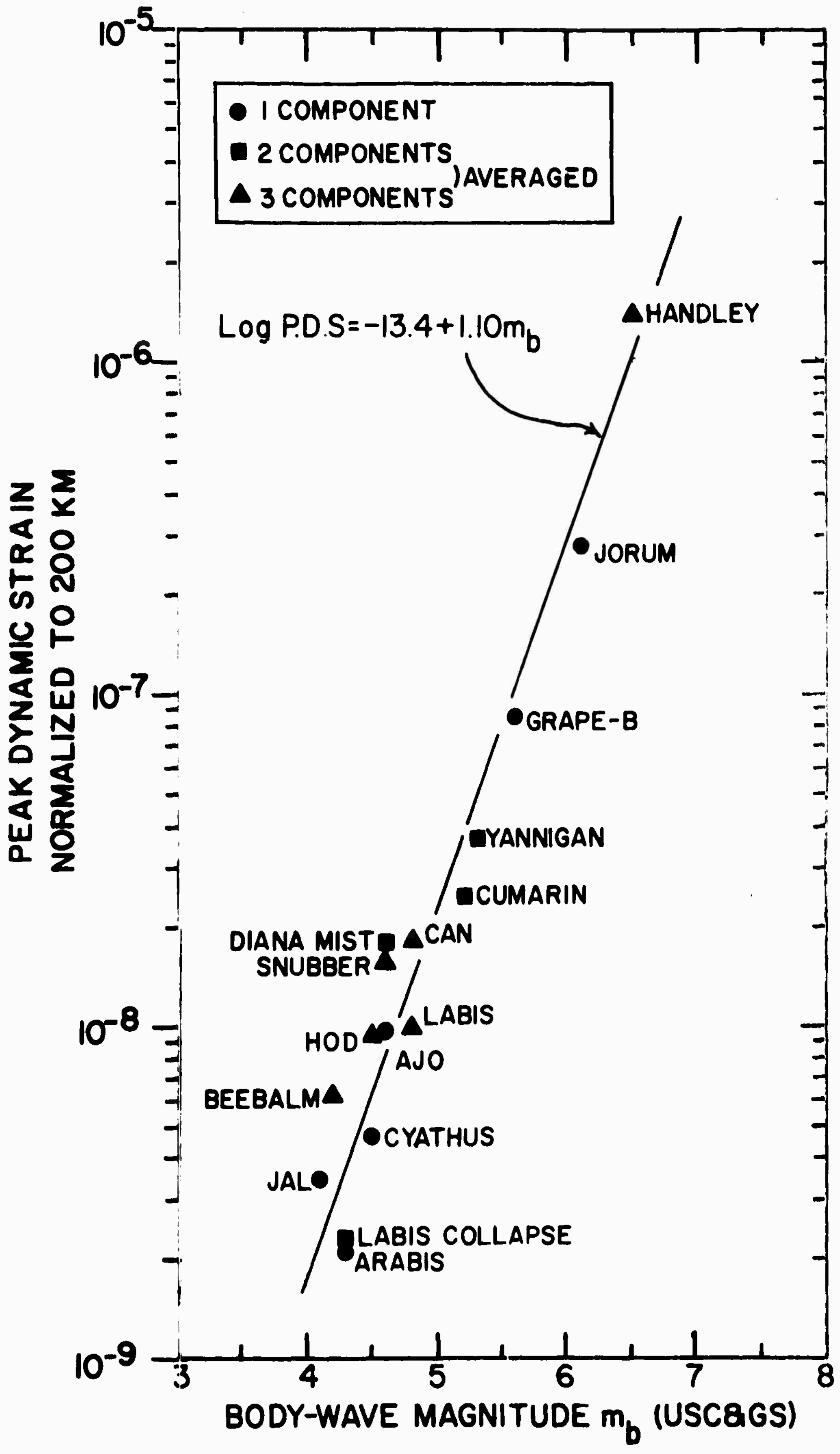
Figure 1. Maximum peak-to-peak dynamic strain recorded at Round Mountain as a function of body-wave magnitude m_b taken from the U.S. Coast and Geodetic Survey's Preliminary Determination of Epicenters. When data from more than one component are available, the readings are averaged. Variations of ±50% from the average may be seen on individual components. The data for the 2 largest explosions must be regarded as conservative, since the transducers are not linear over such large ranges.

Figure 2. Photographs of the strain records from Round Mountain and Mina for the explosion HANDLEY. The Mina record is in the lower right of the figure. The offsets produced by the explosion are indicated. The time scale is 30 seconds per small division on the chart.

Figure 3. Residual strain offsets observed at Mina and Round Mountain for the HANDLEY explosion, showing the relationship of the strain stations to the location of the explosion. The orientation of the strain meters is also shown. The strain ellipse calculated for the Round Mountain data is indicated as deviations from a unit circle of no strain. The individual offsets observed at Round Mountain were N 12.5°W: 8.55×10^{-9} extensional; N 72°W: 5.15×10^{-9} extensional; and N 35.5°E: 4.86×10^{-9} compressional.

Figure 4. Digitized strain data for Round Mountain superimposed upon calculated earth tidal strains. The absolute amplitudes of the calculated tidal strains were scaled for best fit to the observations. No recovery of the strain offsets is apparent from comparison with the theoretical tides. The gaps in the observations are due to a calibration run and a power failure of 28 minutes duration.

Figure 5. Round Mountain strain records for the period 1630 to 1930 GMT (approximately) on March 27, 1970, the day after the explosion (at 1800 GMT on March 26). Although small, offsets can be detected on the N 12.5°W and N 72°W components. The offset on N 35.5°E is smaller, but marginally detectable. The distribution of extensions and compressions is the same as for the explosion itself. The last event is believed to be the principal hole collapse folowing the test.



I COMPONENT
2 COMPONENTS
3 COMPONENTS
)AVERAGED
Log P.D.S=-13.4+1.10m
b
HANDLEY
JORUM
GRAPE-B
YANNIGAN
CUMARIN
CAN
DIANA MIST
SNUBBER
LABIS
HOD
AJO
BEEBALM
CYATHUS
JAL
LABIS COLLAPSE
ARABIS
PEAK DYNAMIC STRAIN
NORMALIZED TO 200 KM
BODY-WAVE MAGNITUDE m
b
(USC&GS)
10-5
10-6
10-7
10-8
10-9
3
4
5
6
7
8

FIG. 1

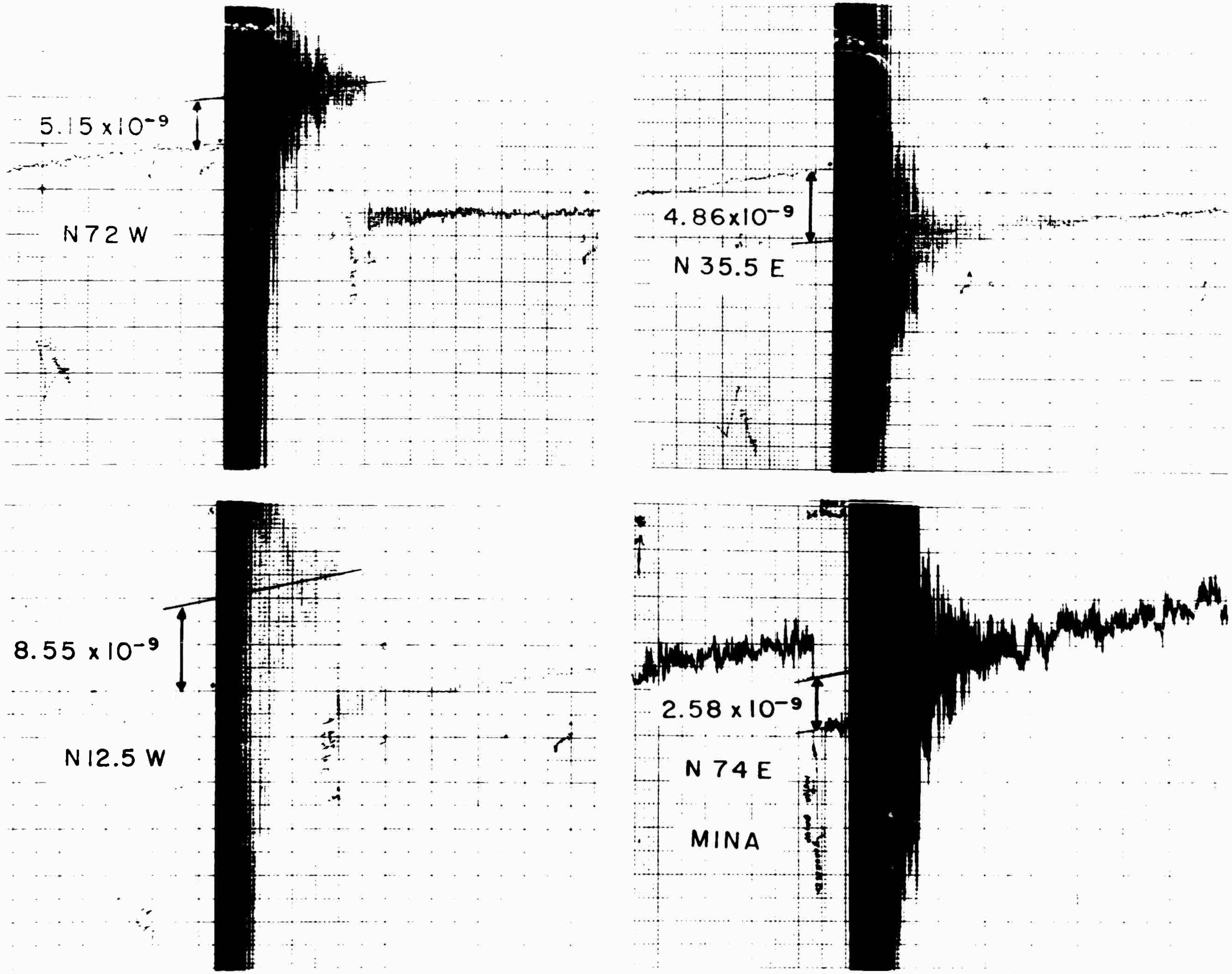
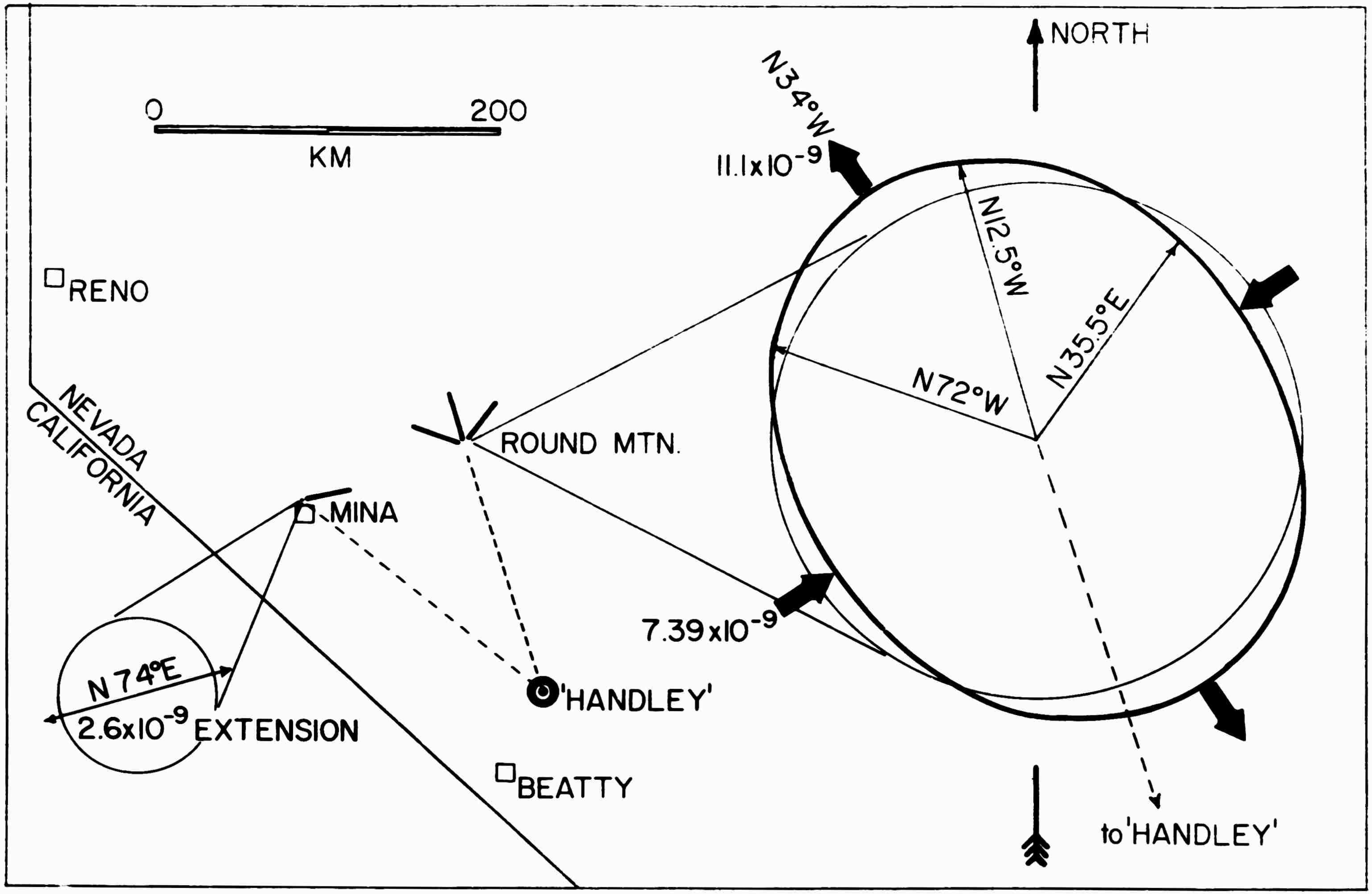

5.15 x 10⁻⁹
N72 W
4.86x10⁻⁹
N 35.5 E
8.55 x 10⁻⁹
N12.5 W
2.58 x 10⁻⁹
N 74 E
MINA

FIG. 2



NORTH
0
200
KM
RENO
NEVADA
CALIFORNIA
MINA
ROUND MTN.
'HANDLEY'
BEATTY
N74°E
2.6x10^-9
EXTENSION
N34°W
11.1x10^-9
N12.5°W
N35.5°E
N72°W
7.39x10^-9
to 'HANDLEY'

FIG. 3

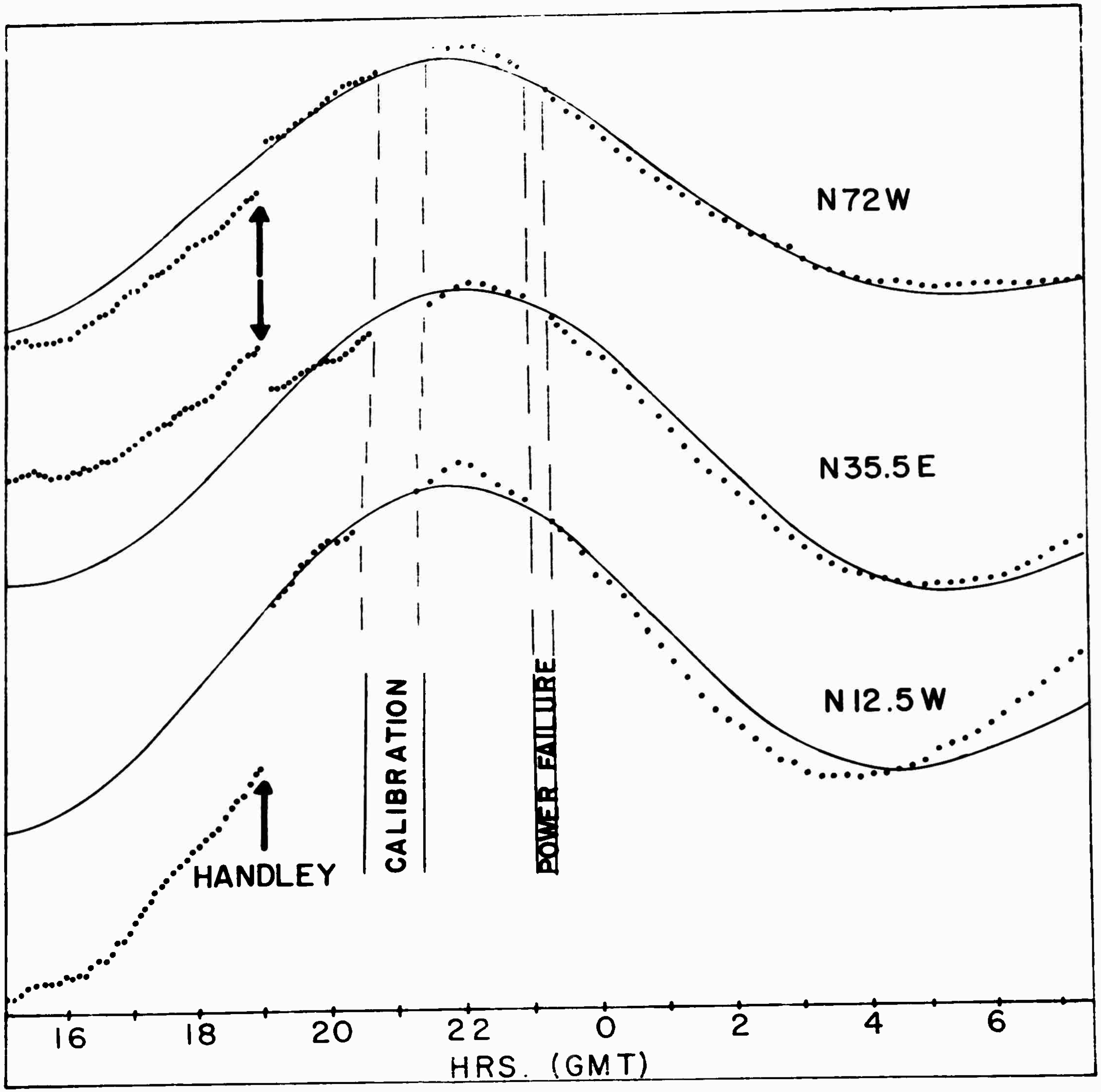

N72W
N35.5E
N12.5W
HANDLEY
CALIBRATION
POWER FAILURE
16
18
20
22
0
2
4
6
HRS. (GMT)

FIG. 4

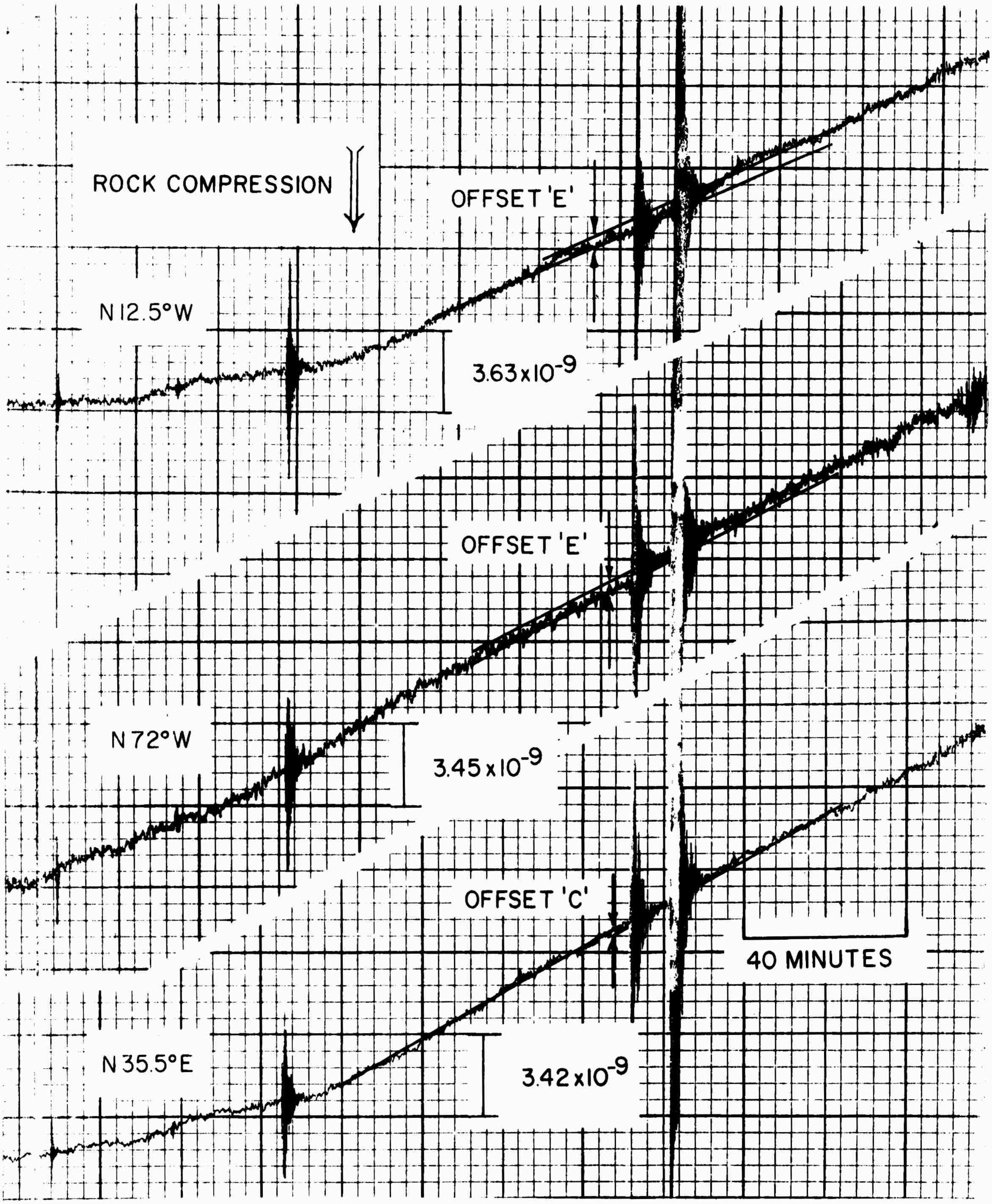

ROCK COMPRESSION
OFFSET 'E'
N 12.5°W
3.63x10-9
OFFSET 'E'
N 72°W
3.45x10-9
OFFSET 'C'
40 MINUTES
N 35.5°E
3.42x10-9

FIG. 5

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) University of Nevada Mackay School of Mines Reno, Nevada 89507	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Seismicity, Mechanics of Faulting and Crustal Structure Within the Basin and Range and Adjoining Provinces

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Scientific.......Final Report

5. AUTHOR(S) (First name, middle initial, last name)

Gary W. Boucher and Alan S. Ryall

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
18 June 1970	17	6

8a. CONTRACT OR GRANT NO. AFOSR 69-1820 b. PROJECT NO. 8652 c. 62701D d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

1. This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
TECH, OTHER	AF Office of Scientific Research (SRPG) 1400 Wilson Boulevard Arlington, VA 22209

13. ABSTRACT

The University of Nevada's 3-component quartz-rod strainmeter installation at Round Mountin, Nevada (38°42.1'N, 117°04.6'W) has recorded a number of underground nuclear explosions at the Nevada Test Site, beginning with the megaton-sized JORUM event September 16, 1969. That explosion, and the larger HANDLEY event on March 26, 1970 both produced static strain off-sets of a few parts in 10^9 at Round Mountain. These offsets did not decay within the first few hours after the explosions. In both cases the strain offsets were in the sense of ground extension radial to the shot point, which is inconsistent with the assumption of a pure compressive source of strain. The strain change ellipse for the HANDLEY event was found to have a major strain axis of 11.1×10^{-9} extensional, oriented N 34°W, and a minor axis of 7.39×10^{-9} extensional, oriented N 34°W, and a minor axis of 7.39×10^{-9} compressional. A single-component strainmeter at Mina, Nevada, (38°26.3'N, 118°9.3' W) was operated for the HANDLEY event, and recorded a strain offset of 2.6×10^{-9} in the direction N 74°E. Strain offsets at the time of the largest collapse events following HANDLEY were observed at Round Mountain. These offsets had the same sense on each component as those following the explosion itself. This is interpreted as support for the hypothesis that the strain changes are tectonic in origin, and the explosion initiates the strain release. Small offsets were observed for three smaller explosions out of a total of 13 studied. The relationship between body-wave magnitude m_b and maximum dynamic strains at Round Mountain may be described empirically by the equation Log S = $-13.4 + 1.10\, m_b$. Because of its high sensitivity and stability, the Round Mountain strain meter is capable of obtaining useful measurements of dynamic and static strain effects of intermediate- to large-sized explosions, at distances ranging from 160 to 200 km.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Three-component quartz-rod strainmeter						
JORUM Event						
HANDLEY Event						